

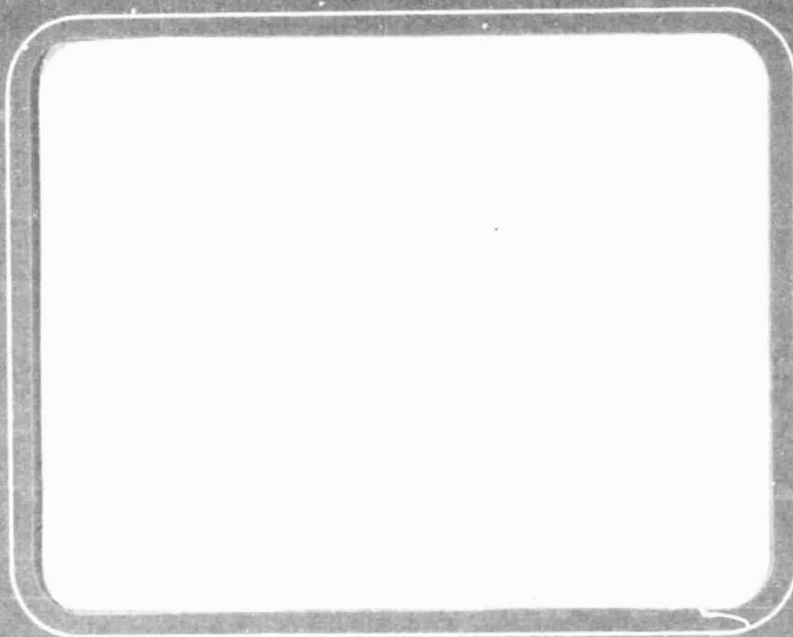
N O T I C E

THIS DOCUMENT HAS BEEN REPRODUCED FROM
MICROFICHE. ALTHOUGH IT IS RECOGNIZED THAT
CERTAIN PORTIONS ARE ILLEGIBLE, IT IS BEING RELEASED
IN THE INTEREST OF MAKING AVAILABLE AS MUCH
INFORMATION AS POSSIBLE



Battelle
Columbus Laboratories

Report



(NASA-CR-161916) STUDY OF METHODS FOR
APPLYING AND ENHANCING TRANSFER FILM
COATINGS OF POLYTETRAFLUOROETHYLENE (PTFE) HC A02/MF A01
TO SPACE SHUTTLE MAIN ENGINE (SSME) HIGH
PRESSURE OXYGEN TURBO (Battelle Columbus

N82-13428

Unclass

G3/37 08508



FINAL REPORT

on

**STUDY OF METHODS FOR APPLYING AND ENHANCING
TRANSFER FILM COATINGS OF
POLYTETRAFLUOROETHYLENE (PTFE) TO SPACE
SHUTTLE MAIN ENGINE (SSME) HIGH PRESSURE
OXYGEN TURBO PUMP (HPOTP) BEARINGS**

to

**NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER**

November 25, 1981

by

J. W. Kannel, K. F. Dufrane, and F. F. Zugaro

Contract No. NAS8-33576, Task 107

**BATTELLE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201**

TABLE OF CONTENTS

	<u>Page</u>
INTRODUCTION.	1
SUMMARY	2
STUDY DETAILS	2
Transfer-Film Machine Development.	2
Single-Ball Burnishing.	2
Multiple-Ball Burnishing.	4
Coating Evaluations.	8
Description of Apparatus.	8
Ball and Race Coating Procedure	12
Tests with Coated Films on Balls.	13
Consideration of Approaches for Improving the Ball Coating Operation.	14
Phosphate Treatment	14
Balls Rougher Than Specifications	14
Balls Precoated with M_oS_2	14
Argon Sputtered PTFE.	15

LIST OF FIGURES

Figure 1. Schematic Illustration of Single Ball Transfer Film Machine.	3
Figure 2. Single-Ball Transfer Film Machine.	5
Figure 3. Ball Rotating Device to Allow Coating the Uncoated Areas.	5
Figure 4. Modified Drill Press Used to Apply Known Loads and Speeds for Multiple-Ball Burnishing Experiments.	6
Figure 5. Schematic Illustration of Ramp Method for Burnishing Three Balls Simultaneously	7

LIST OF FIGURES
(Continued)

	<u>Page</u>
Figure 6. Components of Ramped Method for Coating Balls After Service.	9
Figure 7. Schematic Illustration of Counterrotating Disk Method for Burnishing Eight Balls Simultaneously . . .	10
Figure 8. Schematic Diagram of Apparatus	11

STUDY OF METHODS FOR APPLYING AND ENHANCING TRANSFER
FILM COATINGS OF POLYTETRAFLUOROETHYLENE (PTFE)
TO SPACE SHUTTLE MAIN ENGINE (SSME) HIGH PRESSURE
OXYGEN TURBO PUMP (HPOTP) BEARINGS

by

J. W. Kannel, K. F. Dufrane, and F. F. Zugaro

INTRODUCTION

The NASA efforts are continuing on the improvement and evaluation of long-life turbopumps for use on the space shuttle main engine (SSME). Because of the reusable design, lifetimes of 27,000 seconds (7.5 hours) are being sought, which is a significant extension of the technology developed with all earlier turbopump systems. The mainshaft support bearings of the high pressure oxygen turbopump (HPOTP) are of particular concern because the high speed ($\approx 30,000$ rpm) of the pump combined the target with the extended lifetimes results in an endurance on the order of 1.3×10^6 revolutions.

Good ball bearing performance and life depend critically on adequate lubrication of the ball-race contact region. In conventional liquid-lubricated bearings, a thin film of lubricant is formed between balls and races, which protects them from metal-to-metal contact. In the SSME turbopumps, the only liquid available is the cryogenic liquid, which has, at best, questionable lubricating properties. Consequently, the bearing elements are developed to be lubricated by polytetrafluoroethylene (PTFE) transferred from the reinforced PTFE cage to the balls and races. However, the examination of used bearings and limited bearing testing under earlier tasks of this contract showed that the transferred films were inadequate to provide the needed lubrication. The best performance was found to result from preburnishing the races and balls with PTFE. Significant service lives (on the order of 2 to 4×10^5 revolutions) were attained before the onset of increased torque and wear. Although these were less than the desired service life, the experiments provided encouragement that solid film lubricants applied to the balls and races prior to service could significantly extend the successful time of operation.

The efforts of Task 107 were directed toward evaluating means for applying transferred films reliably. The specific objectives were:

1. Study machine designs and build prototypes which might be utilized to burnish PTFE-type coatings on to a ball or on to several balls surfaces simultaneously, evenly, and uniformly. Ideally, the machine should be suitable for use in a class 100K clean room environment.
2. Demonstrate machine capabilities by burnishing PTFE-type coatings on bearing balls.
3. Document procedures for applying burnished coatings.
4. Conduct bearing test to evaluate coating life.
5. Determine ways to enhance PTFE film transfer in SSME HPOTP bearings.

SUMMARY

Machines were constructed and evaluated for burnishing PTFE on balls for use in the HPOTP. The most positive performance was obtained with single-ball burnishing, but one technique for burnishing three balls simultaneously holds promise. Evaluations of the coatings in an HPOTP bearing of earlier design (employed smaller diameter balls) showed very little life enhancement before high torque and ball and race wear initiated. Other coating techniques, such as molybdenum disulfide combined with PTFE transfer films, hold promise for providing the more durable quantities of solid lubricant needed for the bearings.

STUDY DETAILS

Transfer-Film Machine Development

Single-Ball Burnishing

The machine developed for burnishing single balls with PTFE-type transferred films is shown schematically in Figure 1. The ball is held by

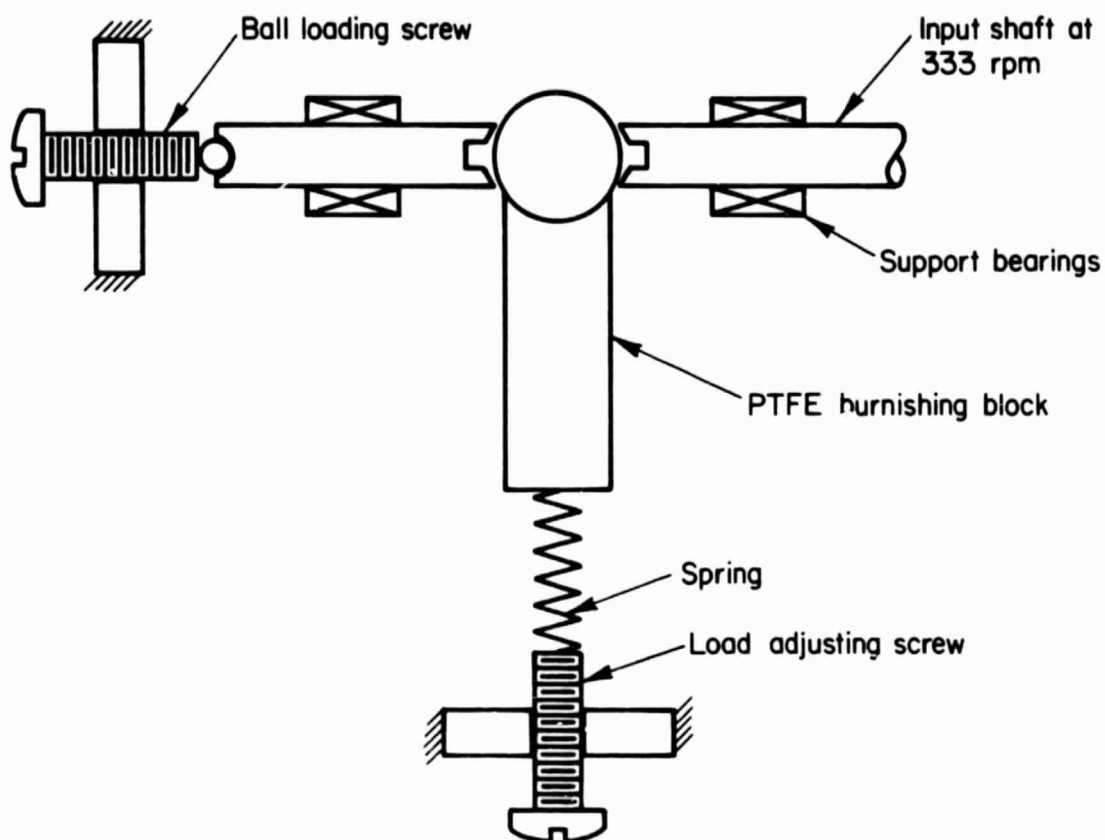


FIGURE 1. SCHEMATIC ILLUSTRATION OF SINGLE BALL TRANSFER FILM MACHINE

friction between two shafts, one of which is rotated at 333 rpm by an electric motor. A hand-operated crank arm and gear box could be used as well to avoid using the electric motor in a clean room environment. A conforming PTFE block is spring loaded against the ball, with the force adjusted by a lead screw. Since the friction grips prevent coating the ball completely in one operation, a swiveling clamp was constructed to grasp the ball on an axis normal to the rotating shafts. After clamping, the shaft load is released and the ball is rotated 90 degrees to expose the non-coated portions. The shafts are then reloaded, the clamp removed, and the remaining portion of the ball is coated.

Photographs of the apparatus are presented in Figures 2 and 3. The apparatus provides a straightforward method of burnishing PTFE-type materials on individual balls. It provides positive ball motion, ease of inspection, and assurance of coating the entire surface (with one 90-degree axis rotation using the rotating device). The primary disadvantage is the restriction of coating balls individually.

Multiple-Ball Burnishing

The possibility of coating several balls simultaneously with a burnished transfer film of PTFE materials was considered in two different approaches. Both used an existing laboratory apparatus based on a modified drill press, Figure 4, to provide rotation and known deadweight loadings. A variable speed drive motor provided speeds from 5 to 180 rpm.

In the first approach, shown schematically in Figure 5, three balls were restrained by a PTFE cage between two PTFE disks. The upper disk was flat and was rotated at 100 rpm. The lower disk was fixed in location and had a conical ball-contact region. The "ramp" region was at a 60 degree angle to the axis of rotation.

The concept of operation was to create an outward force between the balls and cage by the presence of the ramp angle on the lower disks. The resulting sliding under load would provide the required burnishing between the balls and the PTFE. Since the balls would be rotating between a horizontal upper surface and an inclined lower surface, they would be trying to rotate under two different axes of rotation simultaneously. This would be expected to cause the balls to spin, thereby coating the entire surface.

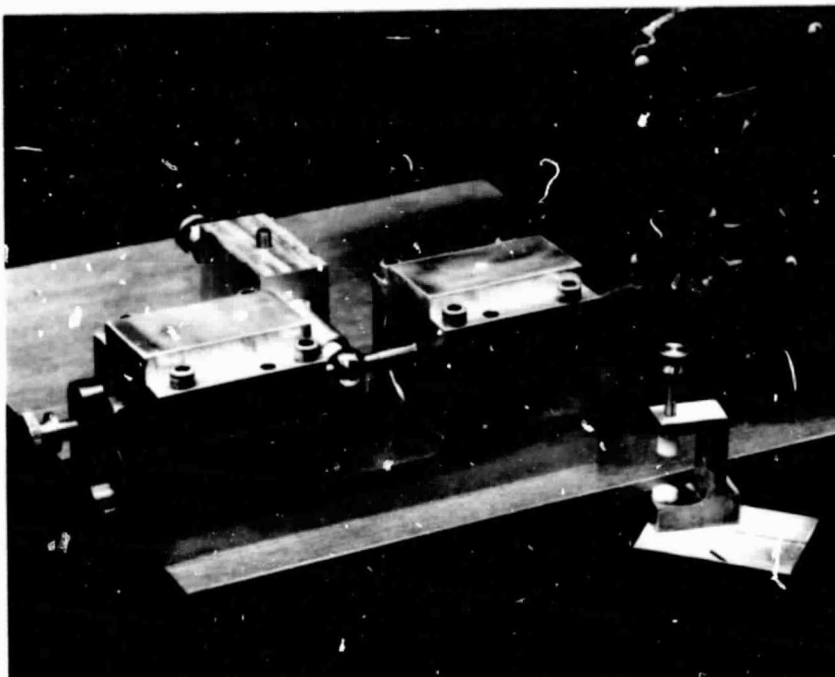


FIGURE 2. SINGLE-BALL TRANSFER FILM MACHINE

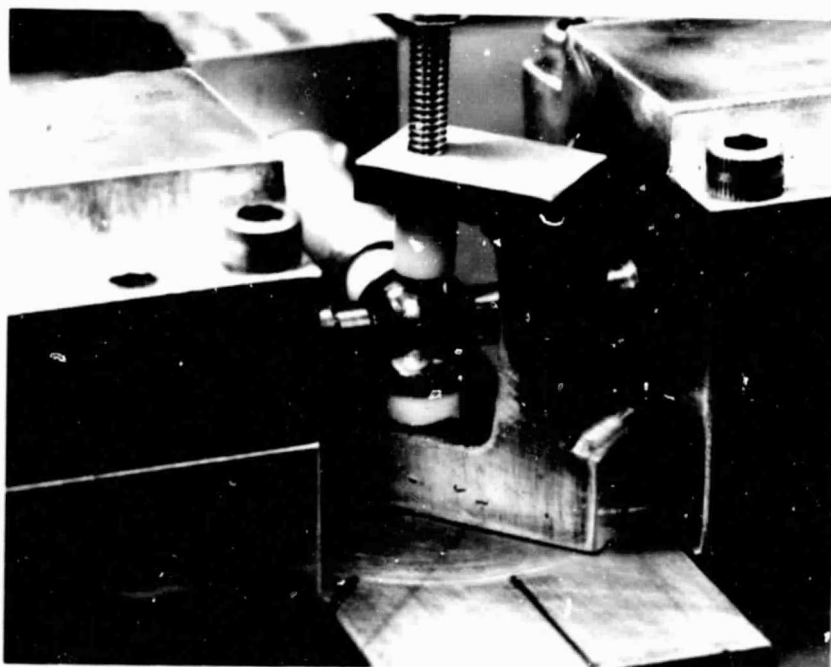


FIGURE 3. BALL ROTATING DEVICE TO ALLOW
COATING THE UNCOATED AREAS



FIGURE 4. MODIFIED DRILL PRESS USED TO
APPLY KNOWN LOADS AND SPEEDS
FOR MULTIPLE-BALL BURNISHING
EXPERIMENTS

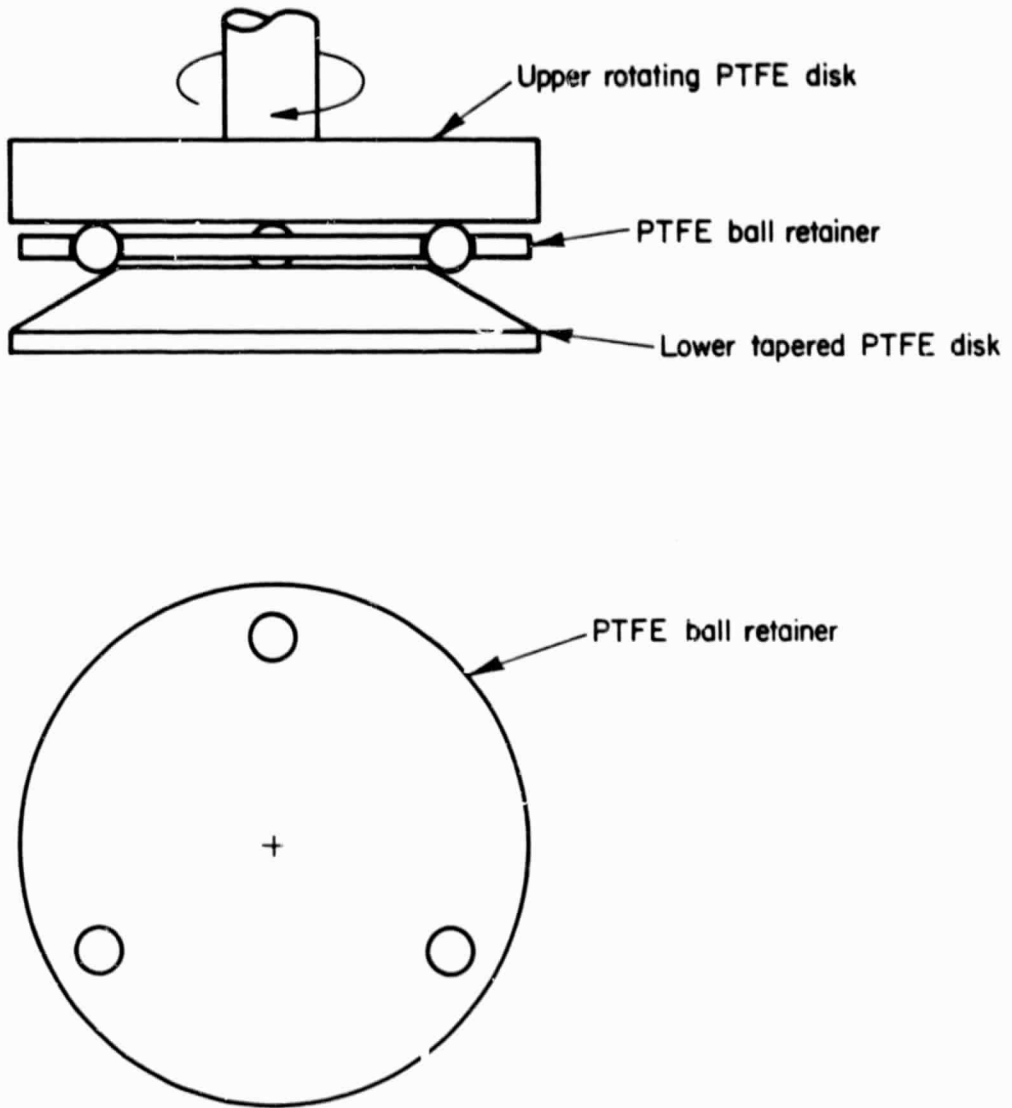


FIGURE 5. SCHEMATIC ILLUSTRATION OF RAMP METHOD FOR BURNISHING THREE BALLS SIMULTANEOUSLY

A photograph of the PTFE components after service is shown in Figure 6. While the basic concept proved to be feasible, the balls tended to band shortly after initiation of rotation. This appeared to be caused by the formation of a worn groove on the ramp, which essentially negated the purpose of the ramp. An example of the groove can be seen in the photograph. Once the groove formed and the balls became banded, further burnishing to coat the entire surface could be attained only by removing load and rotating the balls to a new axis of rotation. Redressing the ramp (the source of the "step" visible in the photograph) renewed its effectiveness, but a new groove quickly formed. A possible improvement may be the substitution of hardened steel disks for the PTFE, which would eliminate the grooving problem. All transferred PTFE would then be required to originate from the cage.

The second approach for burnishing several balls simultaneously used two counterrotating PTFE disks, as shown in Figure 7. Multiple-axis coating was attained by oscillating the ball retainer through a ± 10 degree angle, which produced the necessary ball-retainer loads as well as causing the spin required to expose other axes of rotation. In practice, the disks both developed uneven wear grooves, which appeared to interfere with the ball spin and uniformity of loading. Additionally, the mechanisms required to effect the counterrotation of the shafts and the oscillation of the retainer appeared to be too complicated for practical routine use in a clean room environment. On this basis, the efforts were directed toward the three-ball ramp method and the single-ball method, both of which were described earlier.

Coating Evaluations

With the development of methods for applying burnished coatings to balls, experiments were run to evaluate the effectiveness of the coatings for extended bearing life.

Description of Apparatus

The apparatus used for the evaluations was described in a previous report^{*} and is shown schematically in Figure 8. The lower (slave) bearing

* Kannel, J.W. and Dufrane, K. F., "Transfer Film Evaluation for Shuttle Engine Turbopump Bearings", March 12, 1981.

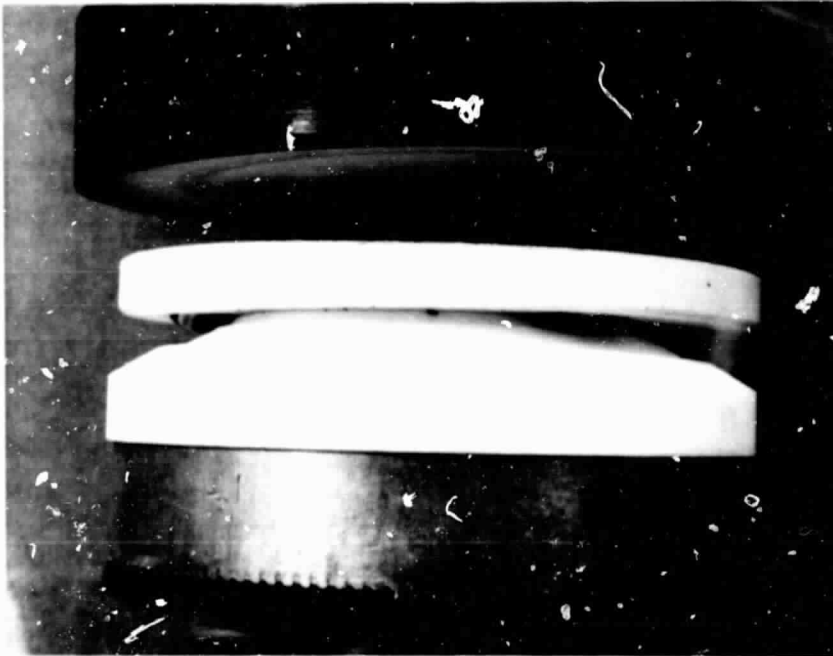


FIGURE 6. COMPONENTS OF RAMPED METHOD FOR
COATING BALLS AFTER SERVICE

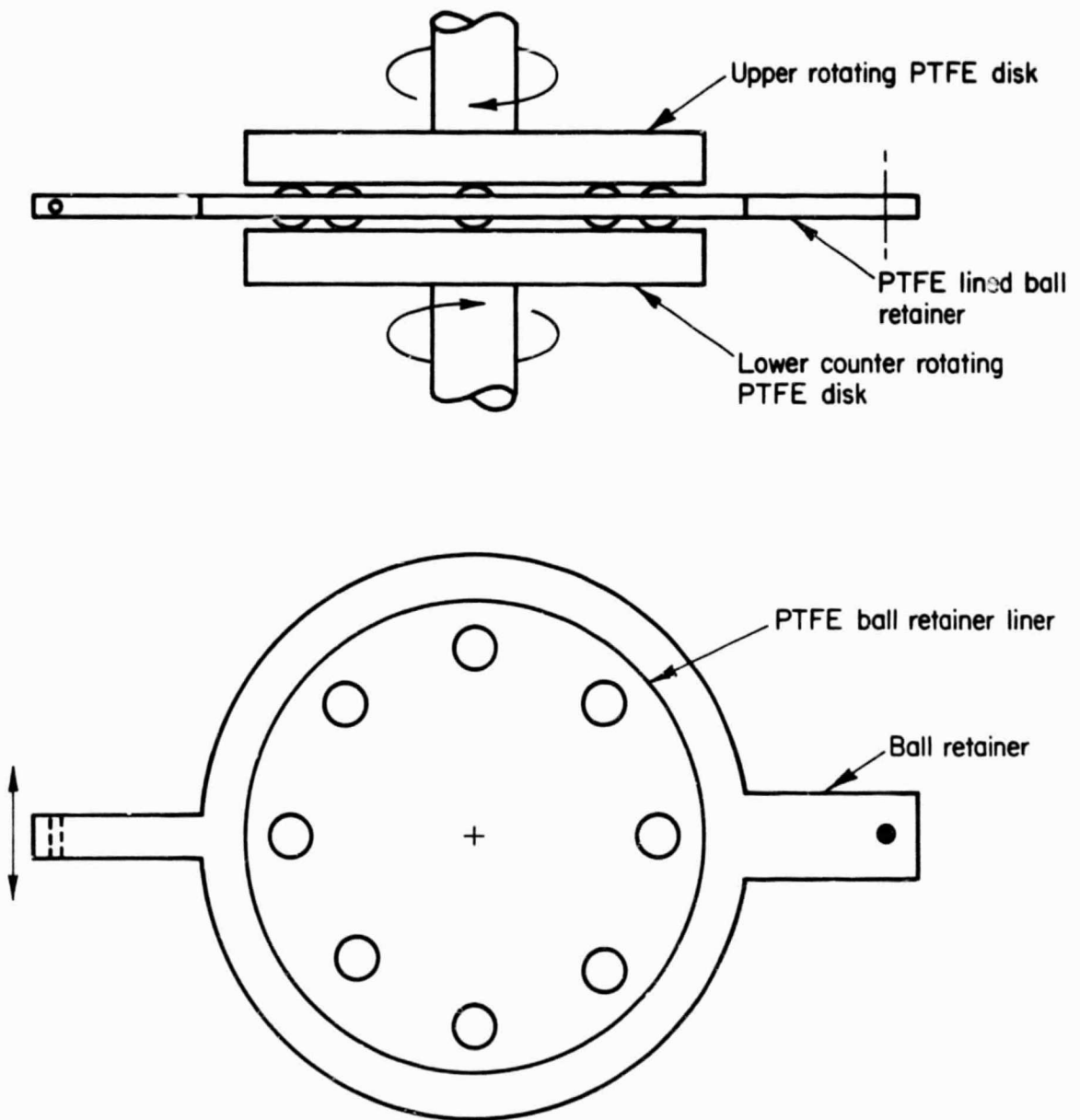


FIGURE 7. SCHEMATIC ILLUSTRATION OF COUNTERROTATING DISK METHOD FOR BURNISHING EIGHT BALLS SIMULTANEOUSLY

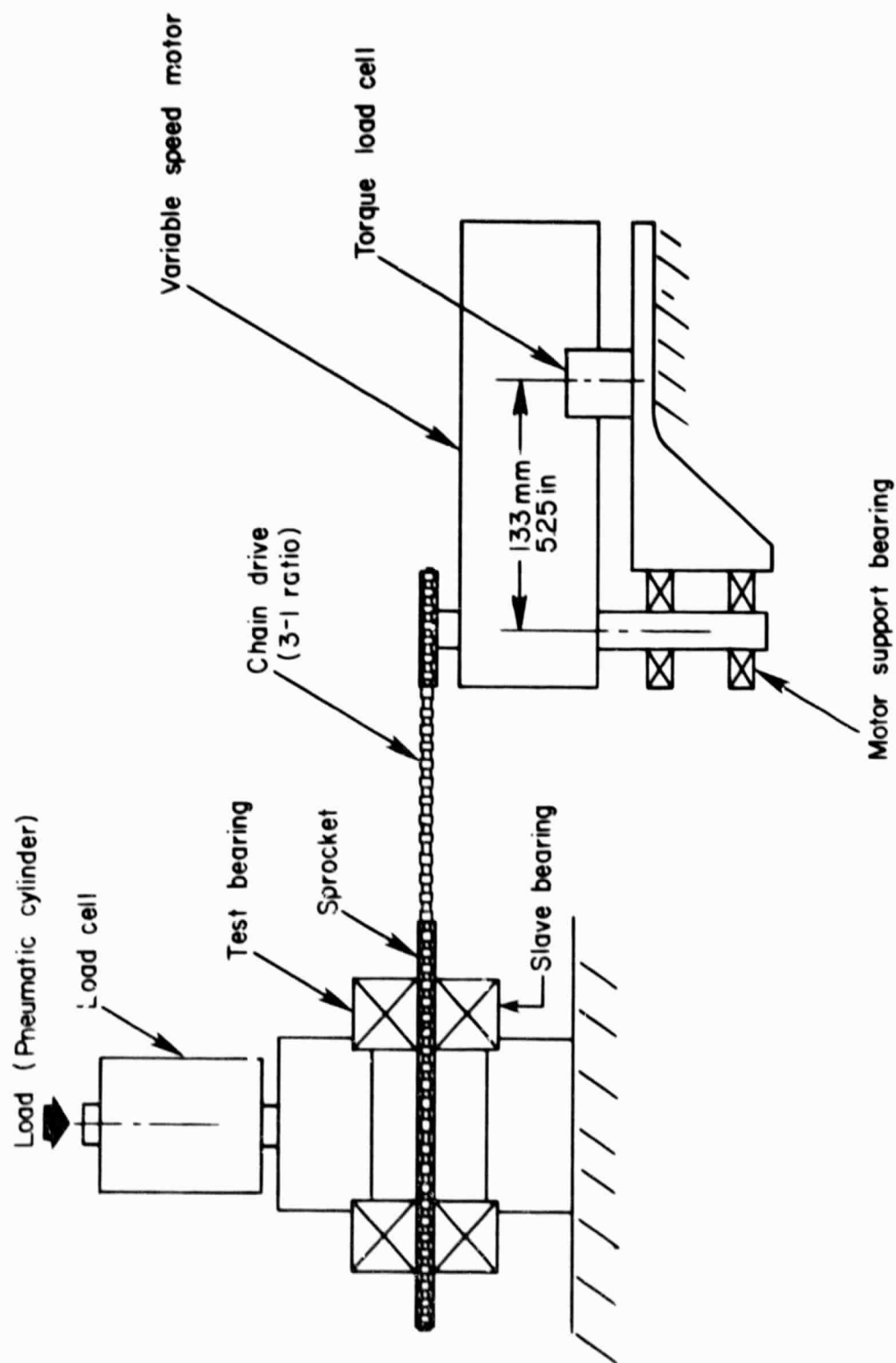


FIGURE 8 . SCHEMATIC DIAGRAM OF APPARATUS

in the apparatus is a grease lubricated bearing and serves to balance the thrust load on the test bearing. A solid plate separates the slave bearing from the test (solid lubricated) bearing. This plate contains a 48 tooth sprocket used to rotate the bearings. The test bearing is loaded by means of a pneumatic cylinder arrangement having a capacity of at least 89,000 N (20,000 pounds) axial load. The bearing load is monitored by means of a load cell situated between the bearing and the cylinder.

The drive motor in the apparatus is a 1 horsepower, variable speed unit and is coupled by means of a chain sprocket (3-1 step down) arrangement to the bearing set; normal bearing speed was 88 rpm. The drive motor is mounted on a pair of "motor-support bearings". This mounting arrangement allows for the motor to move freely about its sprocket center-line. The only pivotal constraint on the motor mount is a load cell located 133 mm (5.25 inches) from the free pivot. This load cell detects the torque originating from the thrust and slave bearing combinations.

The output from the load cells detecting bearing load and bearing torque were continuously monitored by a two-channel strip-chart recorder. An automatic shut-off system was used to terminate the experiments if the torque level exceeded a preset level. This automatic shut-off arrangement allowed for long duration (overnight) experiments to be conducted with the apparatus.

In previous research with the apparatus, the tests with pure PTFE burnished on the races indicated that many cycles (up to 2.7×10^5 revolutions) of bearing operation were possible for an otherwise dry bearing operation under a 4400 N (1,000 pounds) load. In the current task, both balls and races were to be coated for bearing evaluations.

Ball and Race Coating Procedure

In order to enhance the possibility for transfer film coatings, the balls and races were subjected to a rigorous coating procedure. This procedure started by carefully preparing the ball and race surfaces to minimize any contamination which might adversely affect the coating process. This cleaning procedure was as follows:

- (1) The balls and races were cleaned for one hour in a Sweco vibratory mill to remove unknown adsorbed surface

- (2) The balls and races were soaked in toluene for five minutes followed by a tissue (Kimwipe) wipe to remove oil-type contaminations.
- (3) The balls and races were soaked in acetone for five minutes followed by a tissue wipe to remove the acetone.
- (4) The balls and races were soaked in methanol for five minutes followed by a tissue wipe.
- (5) The balls and races were soaked in freon for five minutes followed by tissue wipe to remove remaining surface residues.

All cleaning transfer operations were done using clean-room gloves.

After the cleaning operation, the races were coated with PTFE by the method discussed in the last report. In addition, attempts were made to coat the balls by the procedures described in the previous sections. The primary efforts were with coating procedures shown in Figure 5 using a 40 N (9 pounds) load on the PTFE block for 10 minutes total.

Tests with Coated Films on Balls

The test with the PTFE burnished balls conducted under this task were quite discouraging. The bearing operated for only 1.5×10^5 cycles before a large increase in torque was detected, which is less than previous tests where only the races were coated. Further, the balls in the bearing became roughened as a result of the experiments.

It should be noted that the bearings used in the current experiments were not made to the same specifications as the one used in earlier experiments. The bearing was an earlier design for the HPOTP (Bearing P/N RS007787-011 "D"), which uses smaller balls. The ball size was 10.3 mm (0.406 inch) compared with 12.7 mm (0.5 inch) in the current design, which could increase the contact stress above a critical level for transfer films. It is also possible that other differences existed in the bearing which could account for its poor performance. However, it was obvious that useful bearing life improvement had not occurred as a result of ball transfer film coatings.

Consideration of Approaches for Improving the Ball Coating Operation

The results of the ball coating experiments were discouraging and indicated that no improvement in bearing performance had occurred as a result of the coating efforts. Microscopic examination of the balls coated by the procedures were, in general, inconclusive, but suggested that the PTFE transfer was, at best, spotty and incomplete. As a part of the project, then, efforts were made to evaluate methods to enhance the coating operation. Several different approaches were taken and are discussed below.

Phosphate Treatment

In an effort to encourage PTFE transfer, balls were subjected to phosphate coatings. These coatings were intended both to make the ball surface rougher than normal and to change the surface chemistry in an effort to aid the transfer film coating process. The phosphating, however, did not appear to enhance transfer and further, the ball finishes were very questionable with regards to application in bearings for SSME application.

Balls Rougher Than Specifications

The results of the 1.5×10^5 revolutions bearing test discussed earlier left the balls somewhat rougher than specifications. Efforts were made to determine if just this slight roughening effect might be sufficient to encourage PTFE or Rulon (PTFE + 5% MoS₂) transfer. However, no significant improvement in film transfer occurred.

Balls Precoated with MoS₂

A third approach for enhancing the possibility of surface transfer coatings is to precoat (such as by a sputtering process) the balls with molybdenum disulfide. This approach has apparently been used in other space-craft programs with some success. To evaluate this approach, balls of 12.7 mm (0.5 inch) diameter sputter coated with molybdenum disulfide were subjected to the PTFE burnishing procedure. This burnishing operation was done with the ball device shown in Figure 1.

The results indicated evidence of PTFE transfer and were very encouraging. This improved transfer characteristic with the molybdenum disulfide coated balls may be associated with just a change in surface roughness on the ball, or possibly some other surface chemistry effect. Further work (beyond the current task) is needed to further evaluate this coating and its effect on bearing performance.

Argon Sputtered PTFE

This approach has been suggested by a Hohman Plating representative. Here the PTFE is presputtered with argon to modify the surface layer by removing some of the fluorine atoms, thereby enhancing the transfer process. If this approach is valid, it may represent a reasonable technique to encourage transfer from the cage in the bearing itself as well as a precoating technique. This would involve simply sputtering the cage with argon to enhance the transfer film lubrication process.

A preliminary investigation was made of the technique in this project, and evidence of PTFE transfer was detected.

The preliminary investigation of this technique was made using the following conditions:

Argon pressure = 15 microns

Power density = $0.0124 \text{ watts/mm}^2$ (8 watts/in.^2)

Time = 10 minutes.

The PTFE was then evaluated in the single-ball coating apparatus and evidence of coating enhancement was detected. This approach should be investigated further, either in a future task at Battelle or at NASA.